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(54) METHOD AND APPARATUS TO MAXIMIZE BANDWIDTH AVAILABILITY TO USB DEVICES

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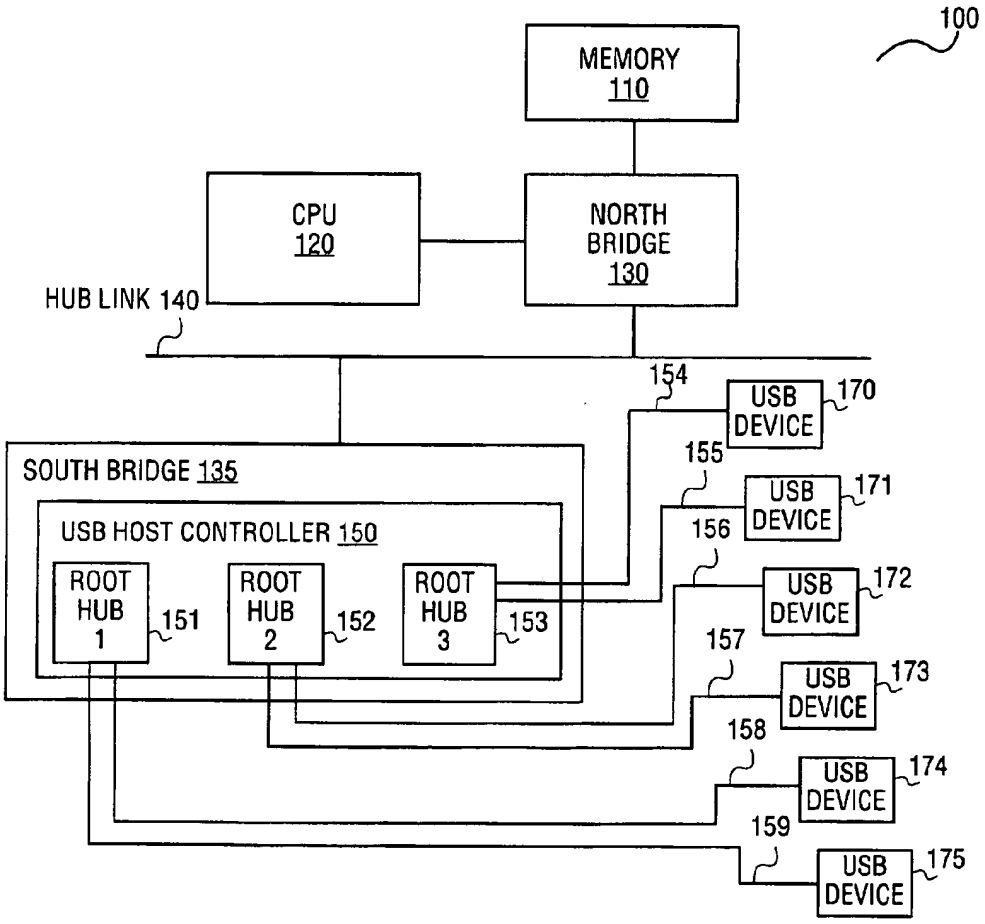
(57) ABSTRACT

A circuit is presented including switches connected to registers. The registers control the switches. The switches are connected to universal serial bus (USB) ports based on a USB device bandwidth balancing process. Also presented is a method determining allocation of USB root hubs. The method also switching USB root hub USB device assignments.



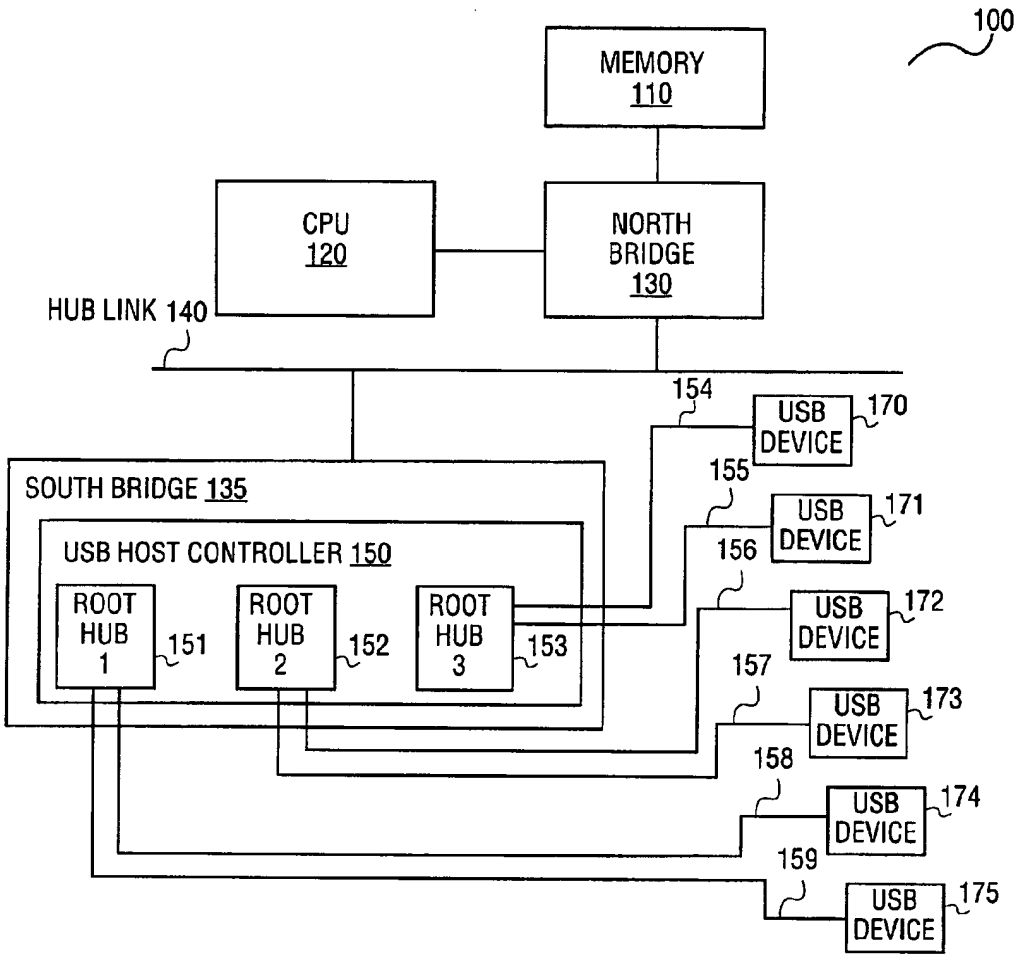

100
MEMORY
110
CPU
120
NORTH
BRIDGE
130
HUB LINK 140
SOUTH BRIDGE 135
USB HOST CONTROLLER 150
ROOT
HUB
1
151
ROOT
HUB
2
152
ROOT
HUB
3
153
154
155
156
157
158
159
USB
DEVICE
170
USB
DEVICE
171
USB
DEVICE
172
USB
DEVICE
173
USB
DEVICE
174
USB
DEVICE
175

FIG. 1

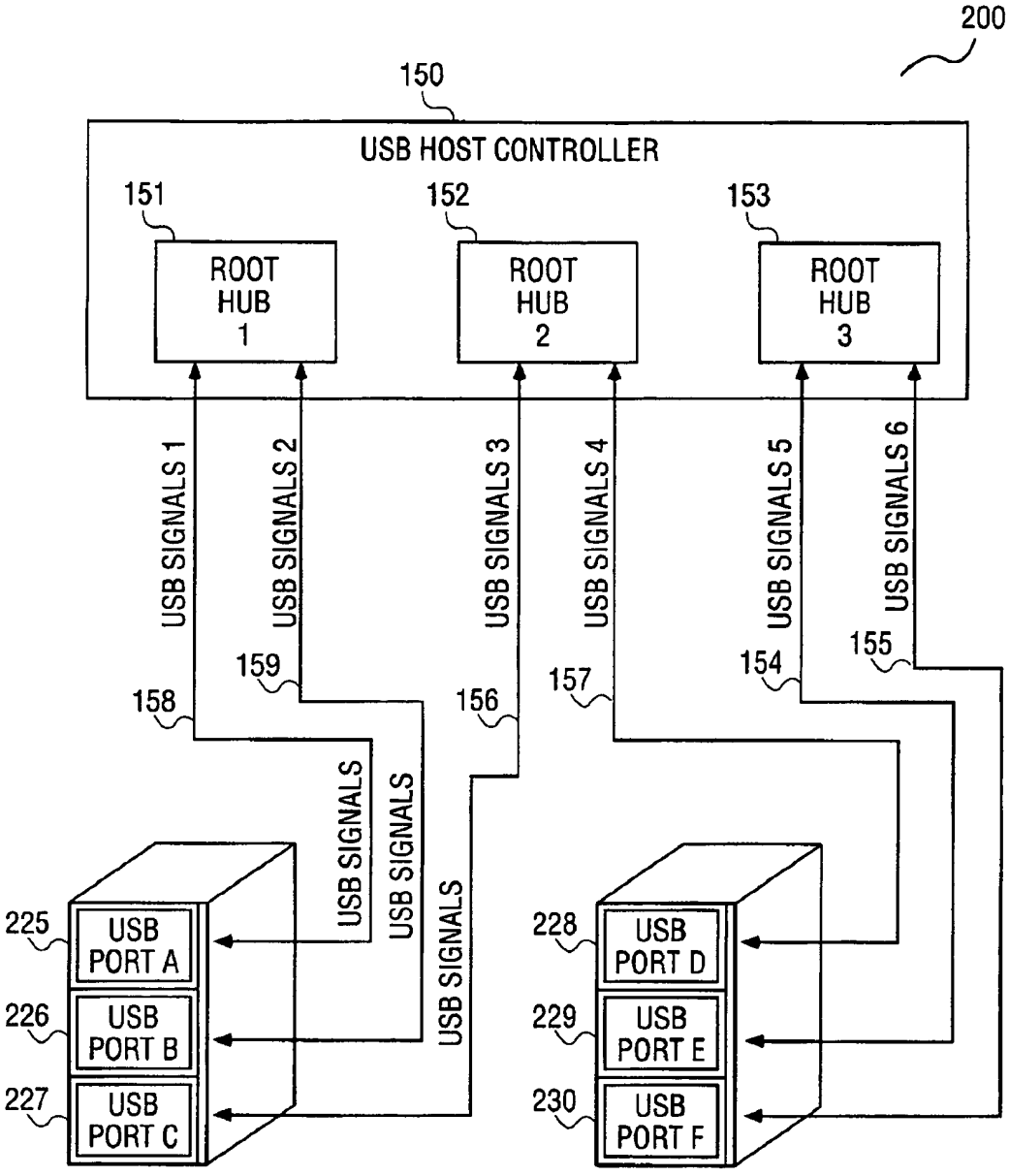

200
150
USB HOST CONTROLLER
151
152
153
ROOT HUB 1
ROOT HUB 2
ROOT HUB 3
USB SIGNALS 1
USB SIGNALS 2
USB SIGNALS 3
USB SIGNALS 4
USB SIGNALS 5
USB SIGNALS 6
158
159
156
157
154
155
USB SIGNALS
USB SIGNALS
USB SIGNALS
225
226
227
USB PORT A
USB PORT B
USB PORT C
228
229
230
USB PORT D
USB PORT E
USB PORT F

FIG. 2

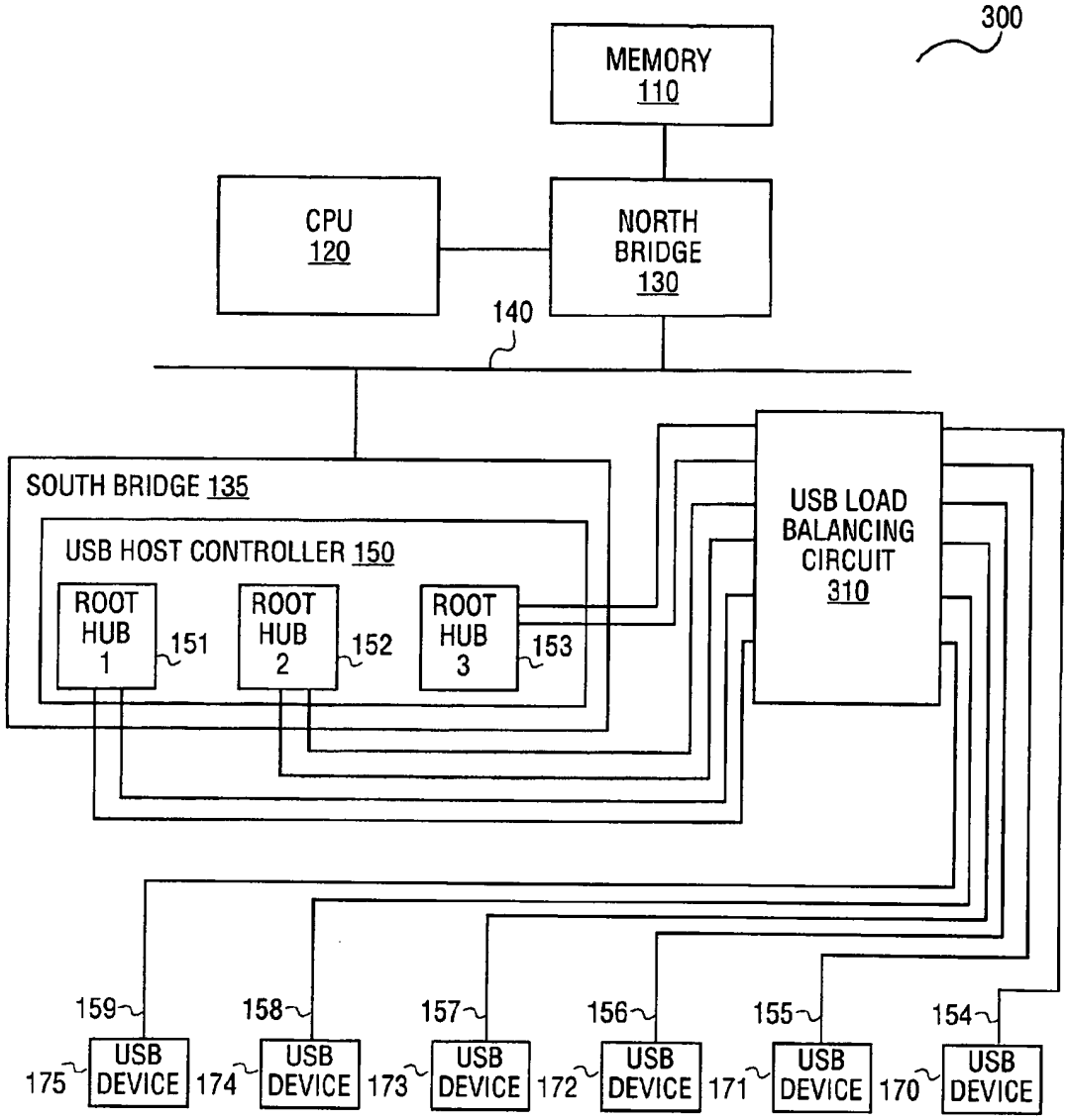

300
MEMORY
110
CPU
120
NORTH
BRIDGE
130
140
SOUTH BRIDGE 135
USB HOST CONTROLLER 150
ROOT
HUB
1
151
ROOT
HUB
2
152
ROOT
HUB
3
153
USB LOAD
BALANCING
CIRCUIT
310
159
158
157
156
155
154
175
USB
DEVICE
174
USB
DEVICE
173
USB
DEVICE
172
USB
DEVICE
171
USB
DEVICE
170
USB
DEVICE

FIG. 3

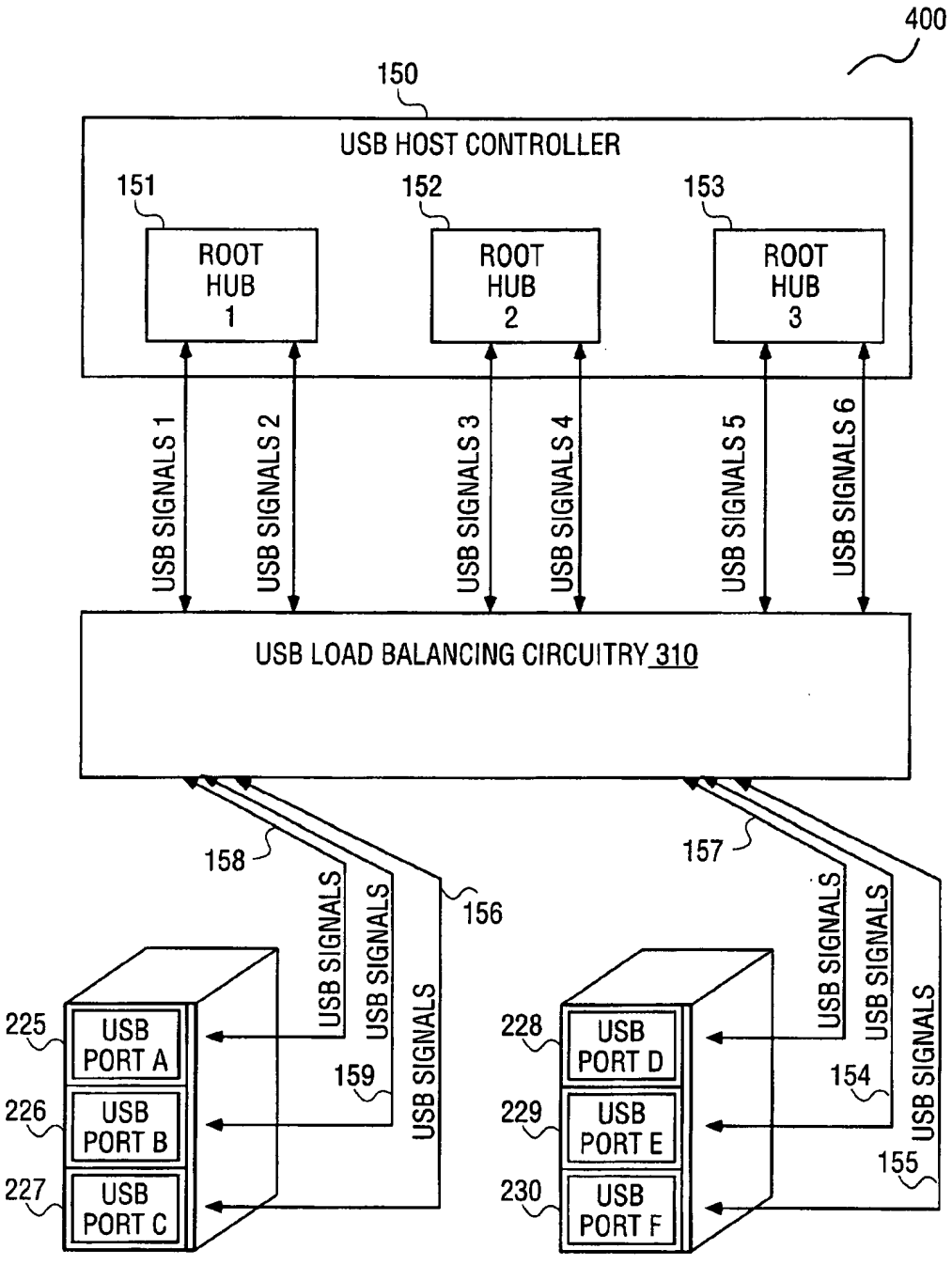

400
150
USB HOST CONTROLLER
151
152
153
ROOT HUB 1
ROOT HUB 2
ROOT HUB 3
USB SIGNALS 1
USB SIGNALS 2
USB SIGNALS 3
USB SIGNALS 4
USB SIGNALS 5
USB SIGNALS 6
USB LOAD BALANCING CIRCUITRY 310
158
156
157
USB SIGNALS
USB SIGNALS
USB SIGNALS
225
226
227
USB PORT A
USB PORT B
USB PORT C
159
228
229
230
USB PORT D
USB PORT E
USB PORT F
154
155

FIG. 4

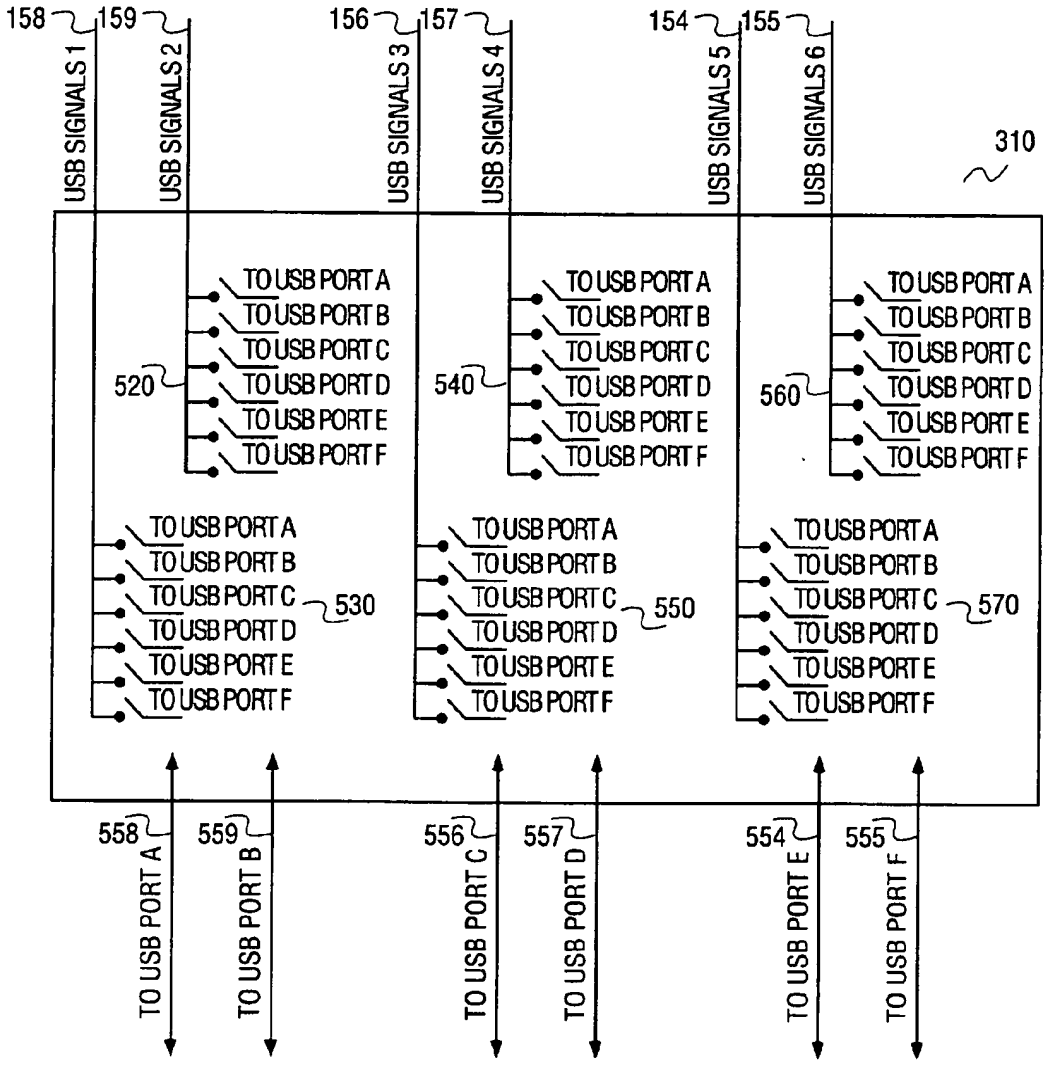

158
159
156
157
154
155
USB SIGNALS 1
USB SIGNALS 2
USB SIGNALS 3
USB SIGNALS 4
USB SIGNALS 5
USB SIGNALS 6
310
520
540
560
530
550
570
TO USB PORT A
TO USB PORT B
TO USB PORT C
TO USB PORT D
TO USB PORT E
TO USB PORT F
558
559
556
557
554
555
TO USB PORT A
TO USB PORT B
TO USB PORT C
TO USB PORT D
TO USB PORT E
TO USB PORT F

FIG. 5

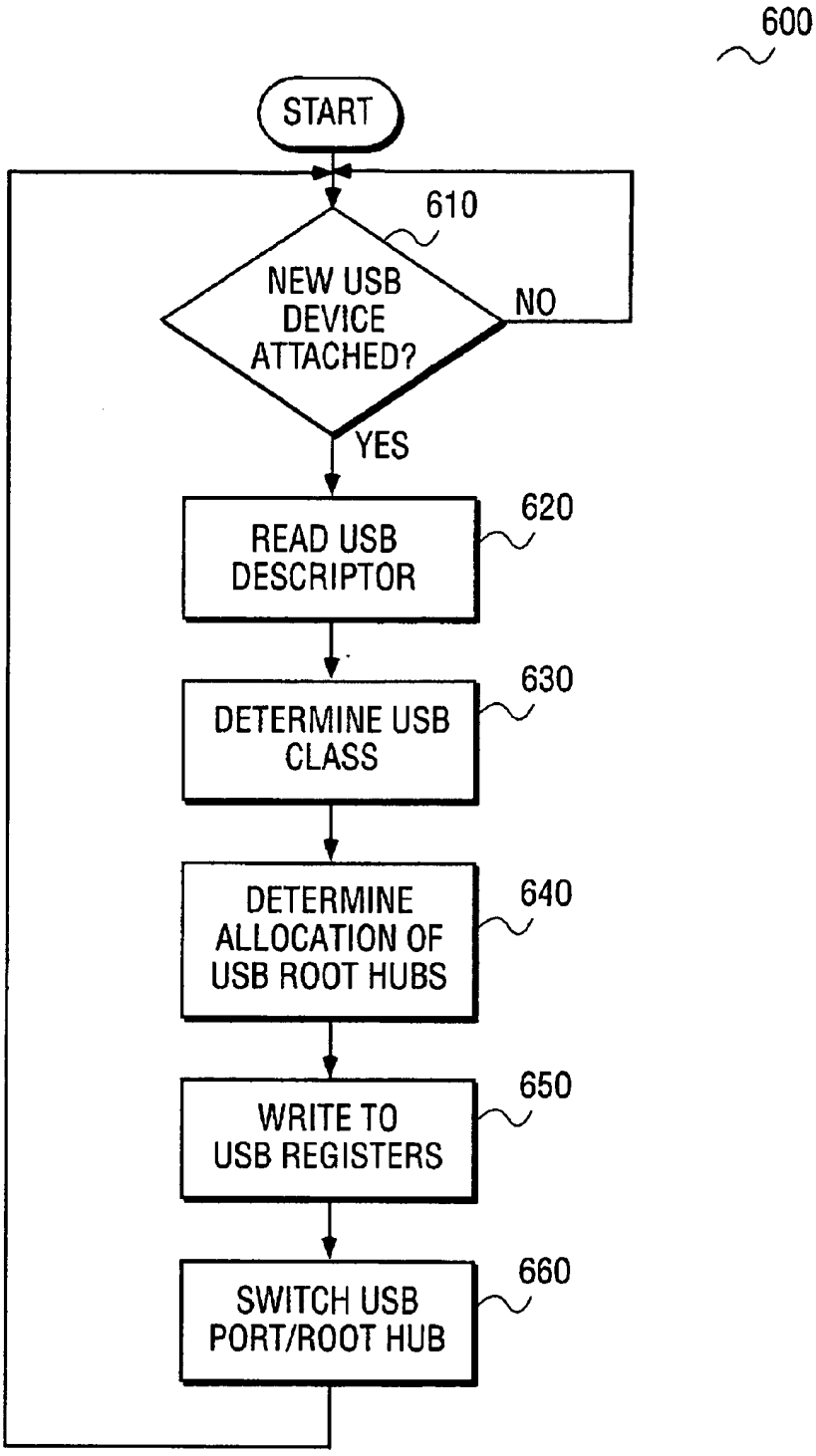

600
START
610
NEW USB DEVICE ATTACHED?
NO
YES
620
READ USB DESCRIPTOR
630
DETERMINE USB CLASS
640
DETERMINE ALLOCATION OF USB ROOT HUBS
650
WRITE TO USB REGISTERS
660
SWITCH USB PORT/ROOT HUB

FIG. 6

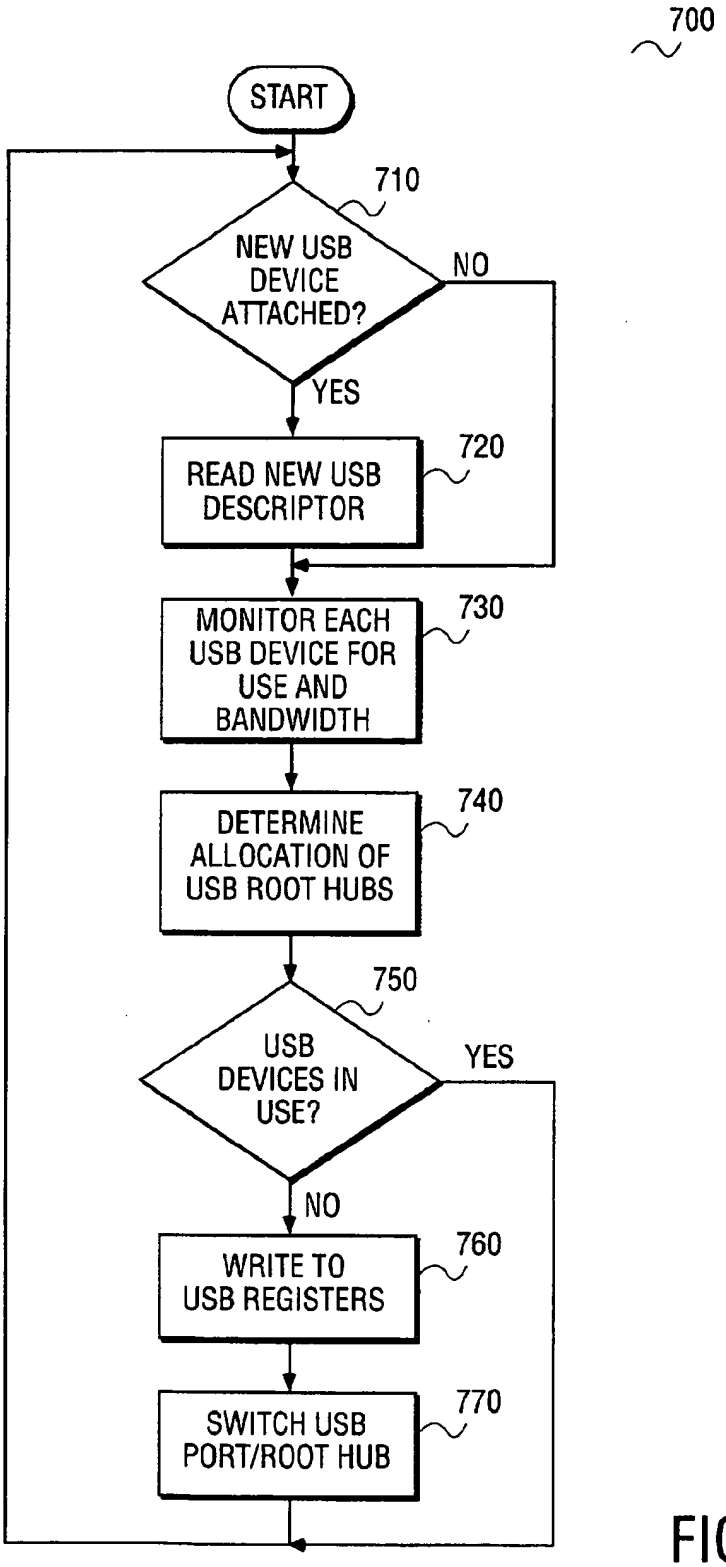

700
START
710
NEW USB DEVICE ATTACHED?
NO
YES
720
READ NEW USB DESCRIPTOR
730
MONITOR EACH USB DEVICE FOR USE AND BANDWIDTH
740
DETERMINE ALLOCATION OF USB ROOT HUBS
750
USB DEVICES IN USE?
YES
NO
760
WRITE TO USB REGISTERS
770
SWITCH USB PORT/ROOT HUB

FIG. 7

METHOD AND APPARATUS TO MAXIMIZE BANDWIDTH AVAILABILITY TO USB DEVICES

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention relates to universal serial bus (USB) use, and more particularly to a method and apparatus of balancing available USB bandwidth for USB devices.

[0003] 2. Description of the Related Art

[0004] In many of todays processing systems, such as personal computer (PC) systems, there exist USB ports for connecting various USB devices. Some of these USB devices are frequently used by PC users. For example, these USB devices may be printers, compact disk read-only-memory (CD-ROM) drives, CD-ROM Writer (CDRW) drives, digital versatile disk (DVD) drives, cameras, pointing devices (e.g., computer mouse), keyboards, joy-sticks, hard-drives, speakers, etc. Some of these devices use more of the available USB bandwidth than others. For example, a USB CDRW is a high bandwidth device, while human interface devices (HID), such as computer mice, keyboards and joysticks, are low bandwidth devices.

[0005] Different standards of USB technology have different bandwidths. For example, Universal Serial Bus Specification, revision 1.1, Sep. 23, 1998 (USB 1.1) devices are capable of operating at 12 Mbits/second (Mbps), and Universal Serial Bus Specification, revision 2.0, Apr. 27, 2000 (USB 2.0; also known as high-speed USB) devices are capable of operating at 480 Mbps. Many users of PCs may not understand how to plug in USB devices into the PCs such that two high-bandwidth devices are not sharing the same root hub. When different devices share the same root hub, the devices also must share/split the bandwidth of the USB.

[0006] For example, if a user wishes to use a USB CDRW and a USB hard drive, (both are high bandwidth devices) and the user plugs both devices into the USB PC ports that share the same root hub, the hard drive and CDRW, will operate at approximately half of their associated maximum speed capability when simultaneously used. Therefore, assuming both devices are USB 1.1 devices, the throughput is divided in half due to a shared root hub. Thus, the devices may only operate at a rate of 6 Mbps when used simultaneously, instead of the maximum rate of 12 Mbps.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

[0008] **FIG. 1** illustrates a system having a universal serial bus (USB) host controller, USB bus, and USB root hubs.

[0009] **FIG. 2** illustrates a USB host controller coupled with input/output (I/O) connectors for USB devices.

[0010] **FIG. 3** illustrates a system coupled with an embodiment of the invention having a USB load balancing circuit.

[0011] **FIG. 4** illustrates an embodiment of the invention coupled between a USB host controller and I/O connectors for USB devices.

[0012] **FIG. 5** illustrates an embodiment of the invention.

[0013] **FIG. 6** illustrates a block diagram of a process of an embodiment of the invention for using a USB class based balancing policy.

[0014] **FIG. 7** illustrates a block diagram of a process of an embodiment of the invention using a USB use and bandwidth consumption based policy.

DETAILED DESCRIPTION OF THE INVENTION

[0015] The invention generally relates to an apparatus and method to best use the available bandwidth of universal serial bus (USB) devices. Referring to the figures, exemplary embodiments of the invention will now be described. The exemplary embodiments are provided to illustrate the invention and should not be construed as limiting the scope of the invention.

[0016] **FIG. 1** illustrates a typical system comprising central processor unit (CPU) **120**, memory **110**, north bridge **130**, hub link **140**, and south bridge **135**. Typically, the chief responsibility of north bridge **130** is the CPU interface. In addition, north bridge **130** may also have controllers for an accelerated graphics port (AGP), memory **110**, and hub link **140**, among others. South bridge **135** is typically responsible for a hard drive controller, USB host controller **150**, an input/output (I/O) controller, and any integrated sound devices, amongst others.

[0017] South bridge **135**, as illustrated, is comprised of USB host controller **150** having root hubs **151**, **152** and **153**. Root hub **151** may be directly coupled to USB devices **174** and **175** via USB bus **158** and **159**, respectively. Root hub **152** may be directly coupled to USB devices **172** and **173** via USB buses **156** and **157**, respectively. Root hub **153** may be directly coupled to USB devices **170** and **171** via USB buses **154** and **155**, respectively.

[0018] **FIG. 2** illustrates USB host controller **150** coupled to USB ports **225-230**. USB devices **170-175** can be coupled to USB ports **225-230**. It can be seen from **FIG. 2** that two devices can be connected to USB ports coupled to the same USB root hub. If two high bandwidth devices are connected to the same hub, the two devices may only operate at half the intended rate. For example, if a high bandwidth device is connected to USB port **225**, and another high bandwidth device is connected to USB port **226**, then both devices will be connected to USB root hub **151**. If USB root hub **151** is using USB 1.1, then the maximum bandwidth is 12 Mbps. If USB root hub **151** is using USB 2.0, then the maximum bandwidth is 480 Mbps. Therefore, both devices connected to USB root hub **151** will share the available bandwidth.

[0019] If a user is not sophisticated in USB technology, the user would not know why the two devices seem to be running at a slower pace, than if separately connected to different root hubs. If the user has six USB devices that she wishes to connect to USB ports **225-230**, the user would have to know each devices capabilities and be able to determine the most efficient way to connect each device to each port. This is compounded if both USB 1.1 and 2.0

technology is included in the same system. For an average PC user this can be frustrating and time consuming.

[0020] **FIG. 3** illustrates a system having an embodiment of the invention. System **300** comprises CPU **120**, memory **110**, north bridge **130**, hub link **140**, and south bridge **135**. South bridge **135** is comprised of USB host controller **150** having root hubs **151**, **152** and **153**. In one embodiment of the invention, USB load balancing circuit **310** is disposed between USB host controller **150** and root hubs **151-153**. Root hubs **151-153** may be coupled to USB devices **170-175** via signals on USB buses **154-159** via USB load balancing circuit **310**.

[0021] **FIG. 4** illustrates an embodiment of the invention having USB load balancing circuit **310** coupled with USB ports **225-230**. By using USB load balancing circuit **310**, USB ports **225-230** are variably connectable to USB root hubs **151-153**. When a device is connected to a USB bus, the device is enumerated by the USB subsystem, i.e. a unique device number (e.g., **1-127**). The unique number is assigned to the device, then the device descriptor is read by the USB host controller. The USB device descriptor is a data structure that contains information about the device and the device's properties. Each USB device typically only has one device descriptor.

[0022] Other descriptors exist such as the configuration descriptor, the interface descriptor, the endpoint descriptor and optional string descriptors. The device descriptor and interface descriptor each contains fields related to device classification. These fields contain the class of the device, sub-class of the device and protocol of the device. These fields are used by a host system to associate a device or interface to a device driver. Some of the device classes are as follows: Display, Communication, Audio, Mass Storage and Human Interface.

[0023] **FIG. 5** illustrates an embodiment of the invention having USB load balancing circuit **310** illustrated in further detail. In one embodiment, USB load balancing circuit **310** comprises switching groups **520**, **530**, **540**, **550**, **560** and **570**. Switching groups **520**, **530**, **540**, **550**, **560**, and **570** are controlled by registers (not shown) in one embodiment of the invention. The registers are software/BIOS controllable in one embodiment of the invention. USB signals on USB buses **154-159** are dynamically routed to particular USB ports based on states of registers.

[0024] In one embodiment of the invention, the register states are retained even when alternating current (AC) power is removed from the device, such as a PC. In one embodiment of the invention the switching of each port has a unique default state in an event when controlling registers do not yet have information. In one embodiment of the invention, a software driver or software utility can be used to program the registers used by load balancing circuit **310**. One should note that any number of processes and/or algorithms can be used to program the registers used by load balancing circuit **310**. In another embodiment of the invention, the Basic Input/Output System (BIOS) of the PC or device system is used to program the registers. A BIOS is the program which starts up a computer device and communicates between devices in the computer system (such as a hard drive and graphics card) and the operating system. BIOS is normally stored in an erasable programmable read only memory (EPROM) chip.

[0025] In one embodiment of the invention, a USB load balancing policy based on USB device classes is used to allow USB devices to maximize available USB bus bandwidth. Particular classes of USB devices tend to require the same amount of USB bus bandwidth. In one embodiment of the invention, classes of high bandwidth devices are paired with classes of low bandwidth devices to maximize each device's specific bandwidth requirement. The USB device descriptors are read to retrieve the specific class of the device. Based on the USB device classes, specific USB device classes are separated from being connected to USB root hubs with other specific classes.

[0026] For example, in one embodiment of the invention Mass Storage class devices (e.g., hard drives) are separated so they do not run on the same root hub. Other device classes, for example HID class, which uses minimal bandwidth, can be paired to run on the same root hub as a Mass Storage device class device. In another embodiment, classes of low bandwidth devices are allowed to be paired together.

[0027] **FIG. 6** illustrates a block diagram of a process of an embodiment of the invention for using a USB class load balancing policy. Process **600** in **FIG. 6** starts with block **610**, which determines whether a new USB device is attached to a USB port. If a new USB device is attached to a USB port, than process **600** continues with block **620**. If there are not new USB devices attached to a USB port (other than those already attached), then process **600** continues with block **610**. Block **620** reads an attached device's USB descriptor from the USB bus. After the USB descriptor has been read, block **630** determines the USB class type from the read descriptor. Block **640** determines the allocation of USB root hubs based on the USB class type. Block **640** also keeps track of which USB devices are attached to which USB root hubs. For example, in one embodiment of the invention a table is kept with USB class type, USB root hub assigned and USB device.

[0028] In one embodiment, logic determines which USB devices are allowed to connect to the same USB root hub and which USB devices are not allowed to connect to the same USB hub. Then the available USB root hubs are allocated USB devices according to the allowable connections. After the allocation of USB devices is determined, block **650** writes information to registers used by load balancing circuit **310**. The registers control switching of USB root hubs to available USB ports. After the switching occurs, process **600** determines if any additional USB devices have been attached to a USB port. In one embodiment of the invention process **600** dynamically switches USB devices between USB root hubs before the device is placed in use so as to avoid interrupting processes such as writing to a USB hard drive, writing to a CDRW, printing a document, etc.

[0029] In one embodiment of the invention, a use and bandwidth consumption based policy is used to allow USB devices to maximize available USB bus bandwidth. In one embodiment of the invention the use and bandwidth consumption based policy uses a background driver to monitor the amount of use and bandwidth consumption of each USB device connected to the system. Information gathered from the monitoring of the use and bandwidth consumption of each USB device connected to the system is then used to

determine how each device should be connected to the various USB ports to optimize the available USB bandwidth.

[0030] For example, suppose a user has a USB hard drive, a USB scanner, a USB mouse and a USB printer connected to her PC at various input/output (I/O) ports. The background driver monitoring the use and bandwidth consumption of each device returns information that the USB scanner is not being used at the same time as the USB printer, that the USB mouse only requires minimum bandwidth, and the USB hard drive is frequently used. The USB ports are then balanced accordingly. Therefore, the USB hard drive is paired with the USB mouse on a particular USB root hub, and the USB scanner is paired with the USB printer on another USB root hub. Thus, the user does not have to determine before hand, or switch the devices randomly to maximize the available USB bandwidth per USB root hub.

[0031] In one embodiment, USB load balancing circuit **310** does not switch the USB port device allocations until USB devices have completed operations to prevent switching in the middle of USB device use. In another embodiment, the information retrieved from background monitoring is used upon the next system startup to prevent interruptions by switching devices that are currently in use.

[0032] **FIG. 7** illustrates a block diagram of a process of an embodiment of the invention for using a USB use and bandwidth consumption based policy. Process **700** in **FIG. 7** starts with block **710**, which determines whether a new USB device is attached to a USB port. If a new USB device is attached to a USB port, than process **700** continues with block **720**. If there are not new USB devices attached to a USB port (other than those already attached), then process **700** continues with block **710**. Block **720** reads an attached device's USB descriptor from the USB bus. After the USB descriptor has been read, block **730** monitors each USB device connected to a USB port for use and bandwidth consumption. Process **700** continues with block **740** determining allocation of USB root hubs based on use and USB bandwidth consumption.

[0033] In one embodiment of the invention block **740** keeps a table of which USB devices are used or not used with other USB devices, and how much of the available bandwidth each device uses. In one embodiment, block **740** keeps a running average of USB bandwidth consumption per each USB device. Block **740** makes use of bandwidth consumption and USB device usage information to allocate USB devices to available USB root hubs to maximize the available USB bus bandwidth for the attached USB devices.

[0034] In one embodiment of the invention process **700** continues with block **750**, which determines whether the USB devices attached are currently in use. If the attached USB devices are currently in use, process **700** continues with block **710**. If the USB devices that are to be reallocated are not in use, then process **700** continues with block **760**. Block **760** writes information to registers used by USB load balancing circuit **310**. Process **700** then continues with block **770**. Block **770** switches the USB ports to the allocated USB root hub based on device use and bandwidth consumption.

[0035] In one embodiment of the invention process **700** dynamically switches available USB ports when the USB devices to be switched are not currently being used. This is to prevent situations when interruption of a device would cause the loss of data or be inconvenient (e.g., printing documents, writing to hard drives, etc.). In another embodiment, process **700** writes the information to registers used by USB load balancing circuit **310** to be used upon restart of the computer if the same devices are attached to USB ports.

[0036] With the use of USB load balancing circuit **310**, and embodiments of the invention previously described, users of USB systems do not have to manually switch USB devices to maximize the available bandwidth associated with a USB root hub. Also, embodiments of the invention assists users that do not understand USB bandwidth availability or device consumption. Even if users do understand USB root hub bandwidths and device consumption, embodiments of the invention saves time and prevents user frustration by allocating USB devices/root hubs to maximize the available bandwidth to a plurality of USB devices. It should be noted that while examples may have mentioned USB 1.1 and USB 2.0, that the embodiments of the invention are applicable to future USB developments also.

[0037] The above embodiments can also be stored on a device or medium and read by a machine to perform instructions. The device or medium may include a solid state memory device and/or a rotating magnetic or optical disk. The device or medium may be distributed when partitions of instructions have been separated into different machines, such as across an interconnection of computers.

[0038] While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

What is claimed is:

1. A circuit comprising:

a plurality of switches coupled to a plurality of registers, the plurality of registers to control the plurality of switches;

wherein the plurality of switches are coupled to a plurality of universal serial bus (USB) ports based on a USB device bandwidth balancing process.

2. The circuit of claim 1, wherein the USB device balancing process balances USB bandwidth load by USB device class.

3. The circuit of claim 2, wherein the USB device class is determined from a USB device descriptor.

4. The circuit of claim 1, wherein the USB device balancing process to balance USB bandwidth load by USB device use information and bandwidth consumption information.

5. The circuit of claim 1, wherein a plurality of USB signals are routed through the plurality of switches to the plurality of USB ports dynamically.

6. A system comprising:

a processor;

a memory coupled to the processor;

a north bridge coupled to a bus and the processor;

a south bridge coupled to the bus; and

a universal serial bus (USB) bandwidth load balancing circuit.

7. The system of claim 6, wherein the USB bandwidth load balancing circuit comprises:

a plurality of switches coupled to a plurality of registers, the plurality of registers to control the plurality of switches, wherein the plurality of switches are coupled to a plurality of universal serial bus (USB) ports based on a USB device bandwidth balancing process.

8. The system of claim 7, wherein the USB device balancing process to balance USB bandwidth load by USB device class.

9. The system of claim 8, wherein the USB device class is determined from a USB device descriptor.

10. The system of claim 7, wherein the USB device balancing process to balance USB bandwidth load by USB device use information and bandwidth consumption information.

11. The system of claim 7, wherein a plurality of USB signals are routed through the plurality of switches to the plurality of USB ports dynamically.

12. The system of claim 1, the south bridge further comprising:

a USB host controller coupled to a plurality of root hubs, the plurality of root hubs coupled to the USB bandwidth load balancing circuit.

13. A method comprising:

determining allocation of a plurality of USB root hubs; and

switching a plurality of USB root hub USB device assignments.

14. The method of claim 13, further comprising:

reading a USB descriptor for a USB device; and

writing a plurality of USB root hub allocation information to a plurality of registers coupled to a USB bandwidth load balancing circuit.

15. The method of claim 14, wherein the USB bandwidth load balancing circuit comprises:

a plurality of switches coupled to the plurality of registers, the plurality of registers to control the plurality of switches, wherein the plurality of switches are coupled to a plurality of USB ports based on a USB device bandwidth balancing process.

16. The method of claim 15, further comprising:

determining an attached USB device's class;

distinguishing USB device classes;

allowing at least two low bandwidth USB class devices to couple to a same USB root hub;

allowing at least one low bandwidth USB class device and at least one high bandwidth USB class device to couple to a same root hub; and

preventing a first high bandwidth USB class device and a second high bandwidth USB class device to couple to a same USB root hub.

17. The method of claim 16, wherein USB device classes are determined from a USB device descriptor.

18. The method of claim 16, wherein switching the plurality of USB root hub USB device assignments is dynamic.

19. The method of claim 15, further comprising monitoring each of an attached USB device'use and USB bandwidth consumption, wherein the USB device balancing process to balance USB bandwidth load by the USB device's use information and bandwidth consumption information.

20. The method of claim 19, wherein switching USB root hub USB device assignments is dynamic.

21. A program storage device readable by a machine comprising instructions that cause the machine to:

determine allocation of a plurality of USB root hubs; and

switching a plurality of USB root hub USB device assignments.

22. The program storage device of claim 21, further comprising instructions that cause the machine to:

read a USB descriptor for a USB device; and

write a plurality of USB root hub allocation information to a plurality of registers coupled to a USB bandwidth load balancing circuit.

23. The program storage device of claim 22, wherein the USB bandwidth load balancing circuit comprises:

a plurality of switches coupled to the plurality of registers, the plurality of registers to control the plurality of switches, wherein the plurality of switches are coupled to a plurality of USB ports based on a USB device bandwidth balancing process.

24. The program storage device of claim 23, further comprising instructions that cause the machine to:

determine an attached USB device's class;

distinguish USB device classes;

allow at least two low bandwidth USB class devices to couple to a same USB root hub;

allow at least one low bandwidth USB class device and at least one high bandwidth USB class device to couple to a same root hub; and

prevent a first high bandwidth USB class device and a second high bandwidth USB class device to couple to a same USB root hub.

25. The program storage device of claim 24, wherein USB device classes are determined from a USB device descriptor.

26. The program storage device of claim 24, wherein switching USB root hub USB device assignments is dynamic.

27. The program storage device of claim 23, further comprising instructions that cause the machine to:

monitor each of an attached USB device's use and USB bandwidth consumption, wherein the USB device balancing process to balance USB bandwidth load by the USB device's use information and bandwidth consumption information.

28. The program storage device of claim 27, wherein switching the plurality of USB root hub USB device assignments is dynamic.

* * * * *